Change in the runout vector was also apparent in the data from the turbine's non-drive end bearing (not shown). Although the high vibration had occurred only at the non-drive end of the turbine, matching changes in the runout vectors at either end of the turbine suggested that rotor bow was the problem. When this turbine was run down prior to the first, aborted startup, the rotor was hot, and sat at rest for several minutes before it was restarted. When a hot shaft sits in the bottom of a bearing, its bottom side cools more than its upper side, causing it to bow slightly. A slight, thermally-induced bow in a rotor weighing several hundred pounds can create a high unbalance force at operating speed, with corresponding high vibration amplitudes.

Compressor startup data from the successful second startup gives us further insight into this machine train. In Figure 7 are two compensated 1X polar plots: on the left from the compressor's drive end, and on the right, from its non-drive end. As speed increases, corresponding data points on each plot follow a similar path, indicating that the 1X vectors are generally in-phase. Maximum vibration amplitude occurred at approximately 5300 rpm, accompanied by a 90° phase shift. These are all characteristic of the first balance resonance. At 8680 rpm, the compressor operates well above its first balance resonance.

During the second startup, the unit had been run at 5300 rpm for approximately three minutes. Notice in Figure 7 that the drive end (left plot) 1X vector decreased in amplitude in a stepwise fashion at approximately 5363 rpm. The decrease in vibration was likely due to a decrease in the thermally-induced turbine rotor bow, transmitted through the coupling to the compressor. This, and the evidence contained in the spectrum cascade and Bode plots, indicate that the slow roll period prior to runup was not sufficient to remove the thermal bow. Therefore, our first recommendation was that the slow roll period for a "hot" start be increased from three to fifteen minutes.

The high speed soak, at 5300 rpm, is at the first balance resonance of the compressor rotor. The compressor and turbine appeared to be well-balanced during these tests. If the compressor rotor had not been well-balanced, higher vibration amplitudes caused by sustained operation at the first balance resonance (5300 rpm) would probably have damaged the compressor labyrinth seals. Therefore, our second recommendation was to change the high speed soak speed to 3500 to 4000 rpm, to limit vibration amplitudes during this phase of a normal startup.

Conclusion

No single data presentation format fully characterizes machinery behavior. Different formats emphasize different characteristics. Using each data format appropriately makes the analysis of vibration more accurate and effective. ■

Proximity Transducer Characteristics

The effectiveness of turbomachinery protection systems over the past thirty years owes a great deal to the availability of non-contacting, eddy current proximity transducers. Developed into a practical industrial device by Donald Bently in the mid-1950's, these transducers are used to measure the vibration and position of a machine's rotating parts with respect to its stationary parts.

Unlike seismic transducers, such as velocity transducers and accelerometers, which indirectly indicate rotor vibration, a proximity probe measures rotor position directly. Its output has two components. One is a direct current (dc) level that is proportional to the average shaft position. The other is an alternating current (ac) signal proportional to the instantaneous shaft position.

Figure 1 shows a typical eddy current transducer. The operating end of the transducer usually takes the form of a small threaded rod, which is secured to the bearing cap and adjusted to measure the movement of the rotating shaft relative to the bearing. On critical machines, they are installed in orthogonal pairs, so the motion of the shaft in the plane of the probes can be fully measured.

Figure 2 shows an eddy current transducer system calibration curve for a typical vibration transducer. The proximity probe is connected to its oscillator/demodulator (Proximitor®) module by coaxial cable. The system must be calibrated to the specific material the probe observes, usually AISI 4140 steel. The usual sensitivity is 7.87 mV/μm (200 mv/mil). The frequency response of the transducer system is dc to 10 kHz, and its total linear range is approximately 2.54 mm (100 mils). The American Petroleum Institute publishes API Standard 670 to set common design criteria for eddy current displacement transducers and the monitoring systems to which they are connected. ■

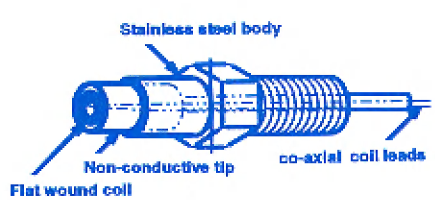

Figure 1

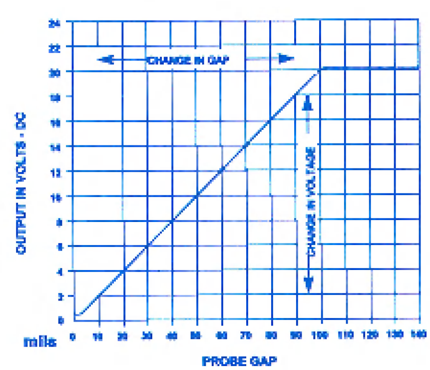

Figure 2